

Analysis of South China Sea Shelf and Basin Acoustic Transmission Data

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LONG-TERM GOAL

My long-term research objectives are: (1) The characterization of meso to internal-wave-scale oceanographic processes that influence broadband sound transmissions in a coastal environment. Central to the characterization are the formulation of accurate forward relations and the quantification of the sensitivities and variability of the various observable acoustic quantities in relation to environmental differences and changes. (2) The development and improvement of high-resolution tomographic inverse techniques for measuring the dynamics and kinematics of meso and finer-scale sound speed structure and ocean currents in coastal regions. (3) The understanding of three-dimensional sound propagation physics including horizontal refraction and azimuthal coupling and the quantification of the importance of these complex physics in the prediction of sound signals transmitted over highly variable littoral regions.

OBJECTIVES

My current research focus is to complete the analysis of both the shelf and basin acoustic transmission data collected from the Northeastern South China Sea (NE SCS) during the Windy Island Soliton Experiment (WISE). These data were collected between April 2005 and October 2006.

The objectives of the NE SCS shelf acoustic data analysis are twofold: The first is to compare and contrast, in terms of phenomenology and statistics, the sound intensity fluctuations resulting from a transmitted acoustic pulse through nonlinear depression internal waves, nonlinear elevation internal waves and/or a mix of both types of waves. The second is to develop and validate a modified theory which expands upon previously established theories of the statistics of sound intensity fluctuations (Dyer, 1970, and Makris, 1996) by incorporating critical signal parameters and channel characteristics including signal and channel bandwidths, multipath arrival times (separations) and additional bottom-induced variance, all of which control the number of independent intensities/arrivals in the received signal.

The primary objective of the basin acoustic data analysis is to study and characterize the supertidal-to-seasonal-scale impacts of the transbasin nonlinear internal waves on long-range transmission loss. Additionally, a secondary objective is to understand the variability of the observed ambient noise level in the basin and quantify what portion, if any, of this variability is related to the nonlinear internal wave activities/climatology.

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APPROACH

Shelf Transmission: The vertical line array (VLA) data is pulse-compressed, motion-compensated, and analyzed for sound intensity as a function of depth and time. Characterizations of the observed intensity fluctuations, in terms of both phenomenology and statistics, are made. In parallel, the oceanographic measurements obtained by the environmental moorings and the shipboard surveys are analyzed using empirical-decomposition and time-series methods to deduce the space-time structure of the sound-speed changes produced by the internal waves. A coupled normal-mode model (Chiu et al., 1996) is employed to examine the propagation physics by linking the observed sound-speed structure to the observed features and statistical properties of the intensity fluctuations.

Basin Transmission: A hypothesis under this investigation is that a major portion of this acoustic variability is induced by the evolution of the transbasin internal tides and waves that are modulated by mesoscale events and seasonal cycles. The detailed analysis of the basin transmission has commenced in FY08 and will continue through FY09. The basin data is first processed for the pulse arrival structure as a function of transmission time. Motion compensation is applied in the processing. Using these pulse responses, time series of transmission loss and of travel times of arrivals are derived, and then their multi-scale variability analyzed with the aid of all oceanographic data measured along the transmission path over the same one-year period.

WORK COMPLETED

In the shelf experiment, a moored 400-Hz sound source, a moored vertical line hydrophone array, moored temperature strings and a towed Scanfish CTD were employed to obtain simultaneous measurements of the fluctuating acoustic signal intensity and of the variable sound speeds for a period of three days in April 2005. The analysis of this data set was completed in FY08, with experimental, modeling and theoretical results documented in Reeves' Ph.D. thesis. Two manuscripts are currently in preparations for submission to refereed journals.

The basin experiment began in April 2005 and ended in October 2006. It entailed seasonal cruises to maintain a moored source and a moored receiver monitoring the periodic transmissions of a 400-Hz signal across the basin. In FY08, the processing and analysis of the data from the last deployment spanning the period from June to October 2006 have been completed with the results presented at the 155th Meeting of the Acoustical Society of America.

RESULTS

During the Shelf Transmission Experiment, significant variability in the sound-speed field was observed, by a series of environmental moorings along the acoustic path, to be induced by: nonlinear internal tides with a broad (~ 10 km) horizontal scale (referred to as the "long-wave pattern"); and by narrow (< 1 km) high-frequency, nonlinear, internal depression and elevation waves superimposed on the internal tides. Through the use of an empirical sound-speed field and a coupled, normal-mode acoustic propagation model, the phenomenology of the nonlinear internal wave field upon the observed intensity pattern was examined. Analysis of the observed and modeled acoustic intensity time-series indicates that the long-wave pattern dictates, to a large degree, the temporal changes in the vertical structure of the sound intensity level. Furthermore, both measurement and model results show that when the thermocline was rapidly displaced by the nonlinear internal waves, sound intensity fluctuations reached their maximum. Modeling results suggest that these maximums are due to the

scattering of acoustic energy into both higher and lower acoustic modes along the edges of the elevation/depression waves where strong horizontal sound-speed gradients were present.

Another key analysis of the shelf transmission data was to propose and validate an extended statistical theory that relates the observed statistics of the acoustic intensity to the number of resolvable arrivals. The number of resolvable arrivals depends on signal bandwidth and the criteria of “well separated” and was found to vary significantly as the nonlinear internal waves evolve along the transmission path. The theory is found to be pertinent when the temporal length of the window for calculating statistics was expanded sufficiently in order to collect a sample population with the following characteristics: 1) the standard deviation of the estimated number of arrivals is small, and 2) sufficient internal wave events are captured to ensure the phase distribution of the arrivals in the sample population is uniform. Fig. 1 shows the observed dependence of the statistics of sound intensity level fluctuation on the average number of temporally disjoint arrivals and how well the observations fit the extended theory.

Standard Deviation of the In-Situ Sound Intensity vs the Average Number of Resolvable Arrivals (measured over 300 min.)

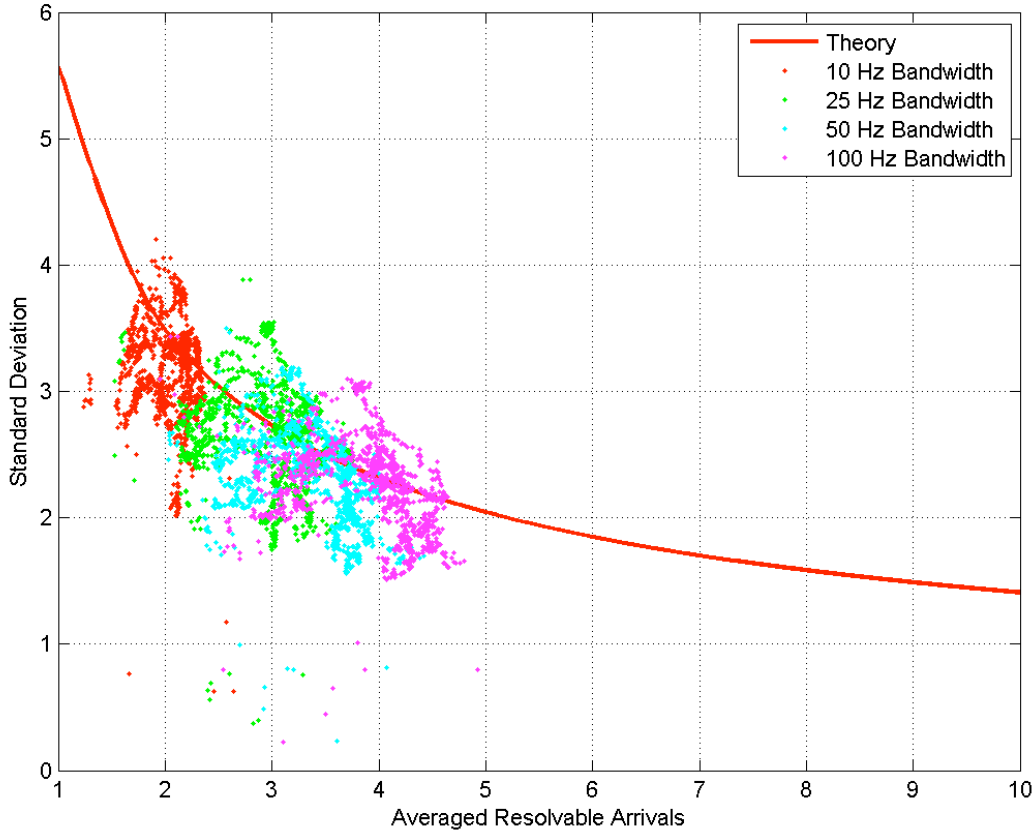


Figure 1. Observed and theorized relations between the standard deviation of sound intensity level and the averaged number of resolvable arrivals. The observed standard deviations (dots) shown were derived from 300-min time windows. Not shown here is the convergence/divergence of the observed standard deviations to/from the theoretical curve (solid red curve) as the length of the time window increases/decreases.

For the basin transmission experiment, important analysis results to date include:

1. Over the NE SCS deep basin, nonlinear internal waves (NLIWs) have no to weak surface signatures, but produce large in situ temperature signatures.
2. Internal tides propagate westward from Luzon Strait and spawn the supertidal-band (> 7 cpd) NLIWs. During June-October 2006, they were formed somewhere between the source and receiver moorings.
3. In the subtidal band (< 0.5 cpd), the observed travel times of the transmitted signal have maximum variations of ~ 50 ms, whereas the observed sound intensity level (SIL) variations are small (~ 1 dB) with a 2-3 day temporal scale.
4. For the observed signal travel times, the variance in the tidal band (between 0.5 and 7 cpd) dominates, producing a standard deviation of 25 ms. The observed temporal change in the travel-time variance exhibits a scalloping behavior (see Fig. 2 upper panel), with highs and lows aligned with periods of high and low internal tide/wave activities.
5. As opposed to the travel times, the variance in the observed SIL is dominated by the fluctuations in the supertidal band with the corresponding standard deviations range from 2 to 3.5 dB (see Fig. 2 lower panel).
6. The slow-scale temporal change in the SIL variance tracks well with the observed mesoscale temperature change in the eastern side of the SCS basin and exhibits a weak scalloping behavior that has time scales consistent with the weekly variability observed in the temperature time series.
7. Consistent with the result depicted in Fig. 1 pertaining to SIL statistics, the observed maximum/minimum SIL variance periods coincide with the absence/presence of an early arrival (see Fig. 3).

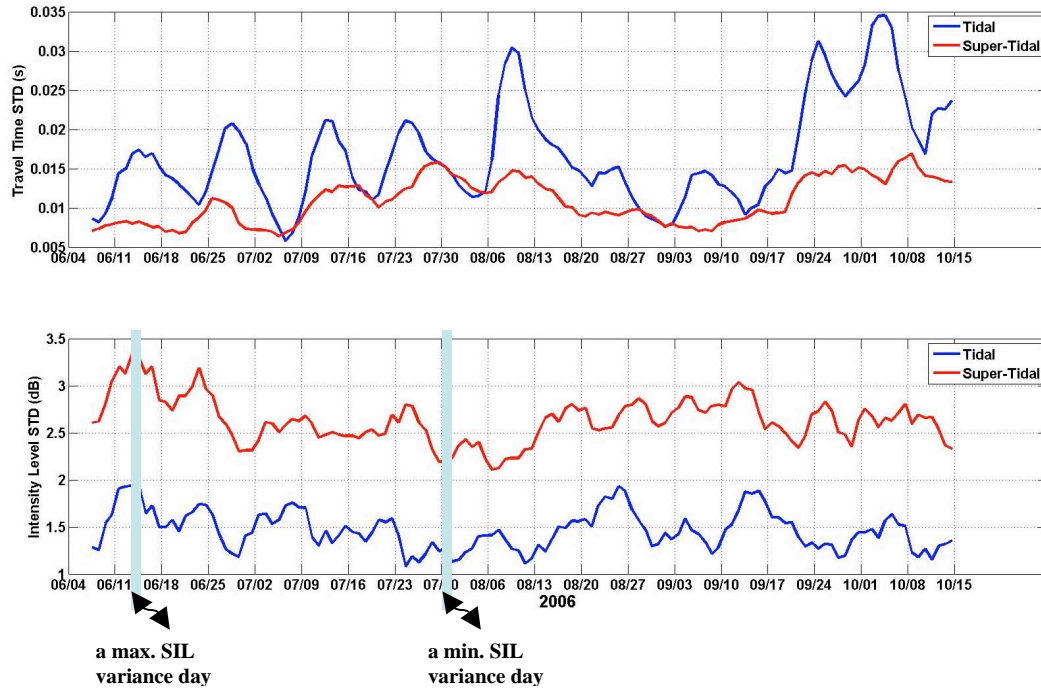


Figure 2. Observed time series of standard deviation of tidal-band (blue) and supertidal-band (red) signal travel time (upper) and intensity level (lower). A maximum and a minimum intensity variance day are highlighted with the corresponding observed arrival structures shown in Fig. 3.

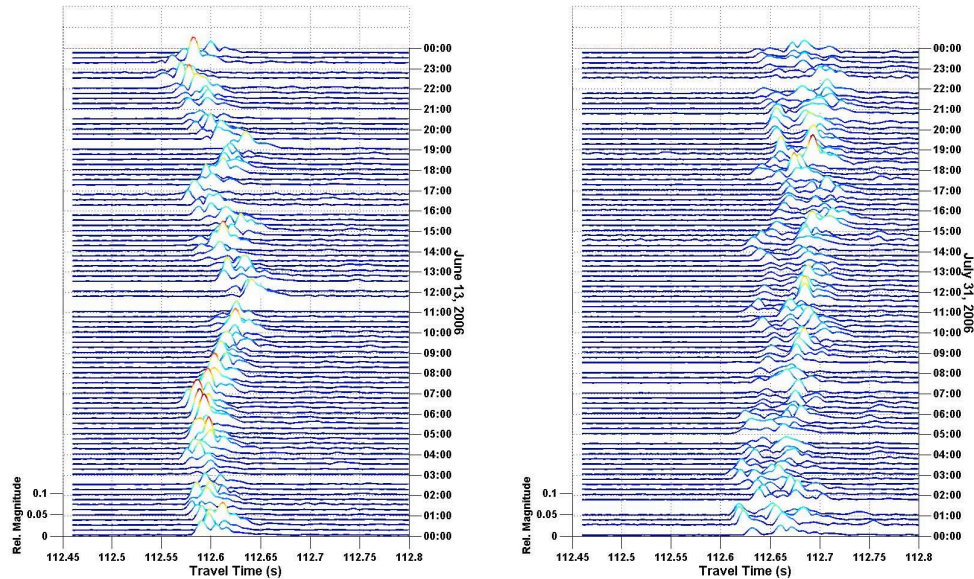


Figure 3. Pulse signal arrival structure measured in two different days, showing the absence (left) and presence (right) of an early arrival.

IMPACT/APPLICATIONS

The oceanographic and acoustic data gathered in this field study should be valuable in helping to create models of shelfbreak regions suitable for assessing present and future Navy systems, acoustic as well as non-acoustic.

RELATED PROJECT

This fully integrated acoustics and oceanography experiment should significantly extend the findings and data from SWARM, Shelfbreak PRIMER and ASIAEX, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

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PUBLICATION

Reeves, J.M., "Statistics of acoustic pulse signals through nonlinear internal waves on the continental shelf of the Northeastern South China Sea," Naval Postgraduate School Ph.D Thesis, March 2008.